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Earth Sciences Report 79-6

Hydrogeology of the Edmonton area (southeast segment), Alberta

R. Stein

Alberta
RESEARCH COUNCIL
Natural Resources Division

Groundwater Department

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1982

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ABSTRACT

The southeast segment of the Edmonton map area (NTS 83H) covers about 4500 km² within the Eastern Alberta Plains physiographic region. Climate is microthermal with long, cool summers. Precipitation averages 430 mm annually and 75 percent falls as rain. Glacial deposits overlie a succession of Upper Cretaceous shales, siltstones, sandstones and coals. Within these deposits, aquifers consisting of sand and gravel, sandstone, and fractured coal are capable of yielding groundwater at rates of up to 8 L/s (100 igpm). Groundwater flow is generally from a western upland area to the east, but permeability variations and local topographic reversals strongly modify this situation. Bedrock hydrochemical zonation is strong and regions of sodium bicarbonate, sulfate, and chloride composition occupy distinct zones with respect to stratigraphy and position within various flow systems.

INTRODUCTION

The Edmonton area (southeast segment) hydrogeological map is part of a series which is nearing completion for the entire province of Alberta. The 1:250 000 NTS map sheets are the basic map units for this series; other scales were used for some areas, however, to accommodate severe data density and quality differences. Remote and sparsely populated areas were mapped at a scale of 1:500 000 while the Edmonton (NTS 83H) area, with relatively large amounts of data and a higher present and anticipated population density, was divided into four quadrants and mapped at a scale of 1:125 000.

The southeast segment of the Edmonton map area comprises about 4500 km², located between longitudes 112°00′ and 113°15′ west and latitudes 53°00′ and 53°30′ north. It contains all or portions of townships 46 to 52 and ranges 14 to 23, west of the fourth meridian.

Groundwater is exploited mainly for domestic and stock watering supplies and only the villages (population in brackets) of New Sarepta (410) and Bittern Lake (134) use groundwater as municipal supplies. Camrose (12 350) derives its water supply by pumping from artificially recharged terrace gravels adjacent to Driedmeat Lake, about eight km south of the map area. Vegreville (4800) obtains its water from the Vermilion River, but a pipeline to carry water from Edmonton is presently under construction. Ryley (550), Holden (390), Hay Lakes (300) and Tofield (1440) use surface water. Use of the area's groundwater resource is highest in the vicinity of Cooking Lake where the rural residential density has grown substantially in the last decade. Here it is not uncommon for up to 30 households per quarter section to be supplied by groundwater.

TOPOGRAPHY AND DRAINAGE

The map area lies within the eastern Alberta region of the interior plains and, with respect to drainage, is located entirely within the North Saskatchewan River basin.

Major elements of the area's topography appear to be bedrock controlled as the main topographic trend follows the northwest to southeast oriented geological strike. The dominant features are:

(a) an upland in approximately the western half of the area underlain by shale, coal and sandstone of the Horseshoe Canyon Formation,

(b) a low-relief, essentially featureless plain to the east of the upland, underlain by Bearpaw shale, and

(c) a gentle rise in topography in the northeastern-most part of the area underlain by a sandy portion of the Belly River Formation.

A hummocky disintegration moraine caps the northern half of the western upland and gives rise to a characteristic undulating to gently rolling knob and kettle topography with numerous irregularly shaped shallow surface water bodies. Elevation reaches up to 792 m and drainage is complex, intermittent, and in places internal.

Other portions of the map area typically have a level to undulating topography associated with ground moraine. Beaverhill Lake (el. 671 m) occupies the lowest portion of the central plain and drains to the north via Beaverhill Creek. The Vermilion River drains the eastern flank of the gentle, eastern topographic rise, and its exit from the map area at Vegreville represents the area's lowest elevation of 634 m.

CLIMATE

According to the Koeppen system of climatic classification (Longley, 1972), the area's climate is microthermal with long cool summers (average temperature of the warmest month above 10°C, and of the coldest month below -3°C; summers with a mean temperature of the warmest month below 22°C and at least four months with mean temperatures of 10°C or more).

Long-term meteorological information is available for three locations within the map area: North Cooking Lake, Vegreville, and Camrose.

The following information has been taken from maps published in the Atlas of Alberta (Alberta, Government and University, 1969) and is representative of conditions averaged over the period from 1931 to 1960 unless otherwise specified.

The mean annual range in temperature is about 32 Celsius degrees. January is the coldest month, with a mean temperature of about -14°C in the southwest and -16°C in the northeast; July is the warmest with an average temperature of 17°C. During the years 1951 to 1964 the last spring frost usually occurred between May 15 and May 31. The first fall frost usually occurred between September 1 and 15 and the usual frost-free period was 100 to 120 days long.

Isohyets shown on the meteorological side map are modified from Longley (1968). Mean annual precipitation varied from under 400 mm in the southeast to just over 450 mm in the west. Approximately 75 percent fell as rain and 270 to 280 mm fell during the growing season (April to August). Average potential evapotranspiration is approximately 530 mm.

GEOLOGY

BEDROCK GEOLOGY

Geology of the bedrock has been reported on by various writers. Most notable of the later studies were those of Allan and Sanderson (1945), Ower (1958), Elliot (1958), and Irish (1970). All proposed various subdivisions of the Edmonton Group, the latest proposal by Irish being the one presently accepted. Shaw and Harding (1949) first used the term Belly River as a formation name and their terminology with respect to the formation and its various members is still in use. Steiner *et al.* (1972) summarized coal occurrences in Upper Cretaceous Alberta strata south of latitude 55 and Campbell (1975) evaluated the coal resources of the Belly River and Horseshoe Canyon Formations in the Tofield-Donalda area. Geological maps available for the area include those of Rutherford (1939a, 1939b) and Green (1972) at scales of 1:253 440 and 1:1 267 000, respectively.

Bedrock subcropping within the map area comprises clastic deposits of Late Cretaceous age. In ascending order the succession is from Belly River through Bearpaw to Horseshoe Canyon Formations. Formation boundaries shown on the geological side map are subcrops terminating on the bedrock surface but are approximate due to difficulties in defining the interfingering boundaries of the Bearpaw Formation. The regional strike is approximately N45°W and beds dip to the southwest at approximately 2.8 and 3.7 m/km in the northeastern and southwestern portions of the area respectively.

The Belly River Formation is nonmarine and consists of grey to greenish grey, thick bedded, feldspathic sandstone, grey, clayey siltstone, grey and green mudstone, and concretionary ironstone beds (Green, 1972). In the map area the formation is from 275 to 300 m thick and contains two distinct zones of increased sandstone content:

1. The lowermost approximately 60 m usually contains from one to three individual sandstones, each up to 15 to 20 m thick, which interfinger with similar thicknesses of marine shales of the underlying Lea Park Formation. These sandstones are grouped and referred to informally as the basal Belly River sandstones. They constitute the lowest stratigraphic horizon for meaningful groundwater exploitation in the map area.
2. The upper, approximately one third of the formation contains the Lower and Upper Birch Lake Members (Shaw and Harding, 1949). Electrologs in the map area usually show a distinct increase in sandstone content at approximately the stratigraphic position of these members, especially from about 60 to 100 m below the top of the formation.

Bearpaw strata consist of marine shales, silty shales, sandstone and bentonite beds that interfinger with sandstone, shale and coal of the overlying Horseshoe Canyon Formation. Due to the interfingering nature of the formation contacts and the similarity of adjacent lithologies, definition of Bearpaw Formation boundaries is difficult. Formation boundaries shown on the

geological side map and on the cross-sections should, at best, be considered approximate and it is highly likely that occasional occurrences of marine strata will be present both above and below the zone indicated.

The lower, approximately 275 m of the Horseshoe Canyon Formation subcrop is in the southwestern portion of the map area. Irish (1970) describes the formation as:

> ...deltaic and fluvial deposits of interbedded and interlensed, fresh and brackish water sandstone, siltstone and shale. Typical sediments consist of soft, grey and greenish grey, grey- and white-weathering, fine grained, bentonitic, feldspathic sandstones; silty, grey, green and brown, bentonitic shales; coal seams and beds of carbonaceous shale ... (and less commonly) ... concretions and beds of hard, brown weathering, calcareous sandstone; thin, nodular beds of red-brown-weathering ironstone; and thin beds of bentonite.

He further states that its outstanding features are:

> ... (1) the lensing and interfingering of strata so that no two sections are identical, (2) the great amount of bentonite in the beds, and (3) the numerous coal seams and zones (Allan and Sanderson list 12 seams)...

SURFICIAL GEOLOGY

Information regarding the surficial geology of all or parts of the area has been published by Bayrock and Hughes (1962) and Bayrock (1972) at scales of 1:50 000 and 1:250 000, respectively. Westgate (1969) reported on the Quaternary stratigraphy of the Edmonton area and Emerson (1977) investigated the surficial geology and morphology of the Cooking Lake Moraine.

Bedrock topography was mapped at a scale of about 1:400 000 by Farvolden (1963) and a small portion in the northwest portion of the map area falls within an area mapped by Carlson (1966) at a scale of 1:50 000.

Surficial deposits within the map area consist almost entirely of till. Bayrock (1972) recognized two types: ground moraine, with local relief of less than 4.5 m, and hummocky moraine, with local relief of more than 4.5 m. The tills consist mainly of reworked local bedrock but contain significant amounts of material from the Canadian Shield and from Devonian rocks outcropping along the shield margin. According to Bayrock (1972), the till comprises approximately equal proportions of sand, silt, and clay but has a gravel content of less than 10 percent. Hummocky moraine is confined to the elevated area situated west of a line joining the west shores of Beaverhill and Bittern Lakes. Numerous lenses of silt, sand, and gravel within the moraine result from sorting of glacial debris by meltwater from the stagnating glacier ice. High local relief and relatively low bulk permeability contribute to the presence of numerous irregularly-shaped surface water bodies over much of the area it covers. Thickness of the area's drift cover varies from less than 3 m to more than 60 m. Areas with more than 15 m of drift cover are restricted to the elevated hummocky moraine and to thalwegs of buried preglacial valleys.

The Vegreville Valley is the largest and starts just west of Cooking Lake, proceeds almost due east, and exits the northern boundary of the map area near Vegreville. The Vegreville Valley is known to contain permeable sand and gravel deposits west of Vegreville and east of Hastings Lake; test drilling, however, has shown such deposits to be discontinuous. Discontinuous, deep occurrences of sand and gravel, often mixed with silt and clay are also present south of the Vegreville Valley (and south of a tributary which follows Katchemut Creek) in the northwestern part of the map area. This sporadic occurrence and the mixed nature of the coarse material both in and south of the buried valley may be the result of two factors:

1. the origin of the Vegreville Valley is local so it cannot be expected to contain large volumes of coarse valley fill, and
2. portions of the coarse material originally present in the valley and along its flanks were moved, mixed, and redeposited south and southwest of the preglacial valley by glacial action.

HYDROGEOLOGY

Previous hydrogeologic studies, portions of which are located in the area, were performed by Domenico (1959) and LeBreton (1963). TransAlta Utilities Corporation (formerly Calgary Power Ltd.) (1975) evaluated the hydrogeology in the vicinity of a major proposed coal strip mine in the south-central portion of the map area. Alberta Environment (1976) commissioned a groundwater evaluation as part of a water level enhancement feasibility study for lakes of the Cooking Lake Moraine. Schwartz (1976) studied the hydrogeology and its relation to various lakes of the Cooking Lake Moraine.

Much of the northern half of the map area was included in a regional groundwater resource evaluation by Alberta Environment (1978).

DATA USED IN MAP PREPARATION

Most of the data used in construction of the hydrogeological map were obtained from water well drillers' reports and chemical analyses filed in the Central Data Bank of the Alberta Research Council Groundwater Department. Information commonly available from drillers' reports consists of location, well construction, lithology, and water levels; occasionally an electrolog, an apparent yield test or a short pumping test are included. Quality of this data is variable and a substantial amount of culling was required.

A number of pumping tests performed by private consulting firms (for purposes of land development in the Cooking Lake area and for coal mine development near Dusty Lake) have become available in recent years. These proved to be invaluable, especially since they are located in areas characterized by considerable variability of groundwater yields.

Existing data were supplemented by:

1. a program in which selected newly drilled water wells were pump tested (with the cooperation of drillers and owners) for as long as five or six hours;
2. a field survey to obtain an even distribution of samples for chemical analysis and water level measurements, to obtain owner estimates of well yields, and to locate hydrogeological field features;
3. structure testhole data provided to the Energy Resources Conservation Board by hydrocarbon exploration companies and electrologs of selected oil wells, and
4. a limited amount of test drilling in the preglacial Vegreville Valley west of Beaverhill Lake to determine drift thickness and the presence or absence of permeable valley fill.

Methods used in evaluating aquifer parameters varied with the type of data available. Transmissivity was determined using the Theis non-equilibrium method where observation wells were available and the Jacob modification of the method where only pumping well data were present. In instances where only length and rate of bailing or pumping along with a total drawdown value could be obtained (as presented on drillers' reports), values of apparent transmissivity were calculated (Farvolden, 1961).

Twenty-year safe yield values were calculated by using the formula:

$$Q_{20} = \frac{TH}{127}$$

where:

Q_{20} = 20-year safe yield in L/s and is defined as the constant rate at which a well can produce continuously so that at 20 years the water level will be drawn down to the top of the producing aquifer;
T = transmissivity in m^2/day;
H = total available drawdown in metres.

Since determination of 20-year safe yield is based on extrapolation of data from pumping tests of relatively short duration, safety factors varying from 25 to more than 50 percent, depending on length of the tests, were applied. Emphasis was placed on data of a reliable and long-term nature. Apparent values of transmissivity and safe yield and qualitative judgments based on geological interpretations and well owner interviews were used as guidance between reliable data points.

AQUIFER PARAMETERS AND YIELD ZONES

Belly River and Bearpaw Formations

Pumping tests are not available for basal Belly River sandstones in the map area. Stein (1976) reported average values of 4.9 m^2/day (330 igpd/ft), 0.5 m/day (11 igpd/ft^2) and 2.9 L/s (38 igpm) respectively for transmissivity, hydraulic conductivity and safe yield for this unit a few kilometres north of the map area. Groundwater yields attributable to this unit are not shown on the main map since its shallowest occurrence is at approximately 150 m in the northeast corner of the map sheet. Although yields can be expected to increase with depth (due to higher available drawdown), water production and use will be limited by increasing gas content and rapidly deteriorating chemical quality.

The zone from approximately 60 to 100 m below the top of the Belly River Formation containing the Birch Lake Members is the most commonly used aquifer in the northeast portion of the map area. It is generally capable of yielding from 0.1 to 0.4 L/s (1 to 5 igpm) and numerous values of apparent transmissivity are available. These range from approximately 0.2 to 2.0 m^2/day (15 to 150 igpd/ft). Production is usually reported to be from 2 to 6 m of sandstone occurring as one to three individual units. In the 0.4 to 2.0 L/s (5 to 25 igpm) yield area east of Beaverhill Lake and south of

the Vegreville buried valley, drillers commonly describe the sandstone units as coarse-grained. Apparent transmissivities of these units are between 2.0 and 5.2 m^2/day (150 to 350 igpd/ft).

In the area of yield of less than 0.1 L/s (<1 igpm) extending southeast from Beaverhill Lake, Birch Lake Member sandstones are too deep to be reached by domestic water wells. Here the only bedrock strata in which water wells can be completed are those of the marine Bearpaw Formation and portions of the Belly River Formation above the upper Birch Lake member. Reports of "dry" wells are common and values of apparent transmissivities are most often in the range of 0.1 to 0.3 m^2/day (10 to 20 igpd/ft). Attempts at drilling through the zone and into the underlying Birch Lake Members result in waters with salinities too high for human and livestock consumption.

Horseshoe Canyon Formation

The most characteristic feature regarding aquifer parameters of Horseshoe Canyon sediments is variability. Coal seams within the lower 150 m interval form the most important bedrock aquifers of the map area and, due to their presence in areas of high rural population density, they are also the most heavily utilized.

A large number of pumping tests are available and, as a result of continuing subdivision of land for rural residential purposes, new tests are continuously being performed. This increased data availability led to a number of revisions of interpreted yield area boundaries as work on the map area progressed; some boundaries on the present map will undoubtedly be proven inaccurate by future data.

The variability results from several factors, related to both depositional and post-depositional processes. An evaluation (TransAlta Utilities Corporation, 1973) of the Camrose-Ryley area for coal mining purposes is the most detailed local geological evaluation of the unit available. Their discussion regarding lithological variability is based on numerous borehole evaluations and reads, in part, as follows:

> Deposition took place under continental-margin conditions where the land surface was gently undulating and where transgressions of bodies of water were repeated and common. Consequently, the layers of fine-to-medium-grained sediments deposited were lenticular, interfingered, gradational, and locally discordant. This situation is most easily observed in the coal seams which are the best horizon markers. Although the coal zones or horizons are relatively continuous, seams within the horizons may split, coalesce, pinch and disappear.

Permeability of the area's coal aquifers results from fracturing. The intensity of fracturing is not uniform over the subcrop area and two sources have been suggested to date:

1. Stein (1976) observed that coals within this zone are capable of producing higher volumes of water where they are present under the prominent, topographically elevated Elk Island High. Fracturing was postulated to be the result of glacial overriding and is most pronounced in this area because the Elk Island High presented greater resistance to, and consequently was subjected to greater stress by, ice movement than the surrounding lower and flatter areas.
2. Matheson and Thomson (1963) showed that rebound in and near river valleys, due to stress relief resulting from removal of overburden during carving of their valleys, can be as much as 10 percent of the valley height and that anticlinal features commonly exist under such valleys. Brecciation and fracturing have been tentatively attributed to this phenomenon and it is possible that coal seams adjacent to the Vegreville preglacial valley (near Cooking and Hastings Lakes) were affected in this manner.

Further complicating factors are that the degree of fracturing decreases with depth of burial and that some coal seams have been removed by erosion during the downcutting of preglacial valleys.

A highly complex situation with respect to coal aquifer distribution and fracturing thus exists in the subcrop area, reflected in high areal variability of transmissivity, hydraulic conductivity, and sustainable yields. Coal fracturing is most pronounced and deepest along both north and south flanks of the Vegreville buried valley. Here it is not unusual for coal seams more than 75 m deep to be extensively fractured and capable of producing water at rates of 2 to 8 L/s (25 to 100 igpm).

Pump-tested wells shown on the main map and in the 2 to 8 L/s (25 to 100 igpm) yield zones were commonly reported to be producing from 0.3 to 5 m of coal, usually present as several seams. Transmissivity and hydraulic conductivity (calculated where total thickness of coal is reported and assuming coal is the only contributing aquifer) are in the ranges of 6 to 720 m^2/day

(400 to 48 000 igpd/ft) and 2 to 290 m/day (40 to 6000 igpd/ft²) respectively; averages are 86 m²/day (5750 igpd/ft) and 44 m/day (900 igpd/ft²). Sustainable yields calculated from these same aquifer tests range from 1 to 150 L/s (12 to 2000 igpm), about one third of these being substantially in excess of 8 L/s (100 igpm). Due to uncertainties regarding boundaries of highly fractured areas and because most pumping tests were of a relatively short duration and conducted at rates far less than the calculated safe yields, no areas with yields greater than 2 to 8 L/s (25 to 100 igpm) are indicated on the map.

Much of the 0.4 to 2 L/s (5 to 25 igpm) yield area shown on the main map is substantiated by "apparent" yield test data or qualitative geological interpretation only. Pumping tests conducted in this area (and shown on the main map) produce from one or more coal seams, 1 to 3 m in aggregate thickness. Transmissivity and hydraulic conductivities range from 1.5 to 45 m²/day (100 to 3000 igpd/ft) and 1 to 25 m/day (22 to 500 igpd/ft²), respectively; averages are 4.5 m²/day (300 igpd/ft) and 4 m/day (80 igpd/ft²). Sustainable yields calculated from these pumping tests vary from 0.4 to 5 L/s (5 to 65 igpm), the average being 1.1 L/s (15 igpm).

Transmissivities calculated from pumping tests in the 0.1 to 0.4 L/s (1 to 5 igpm) yield areas are usually in the range of 0.4 to 2.2 m²/day (30 to 150 igpd/ft). Such values are also thought to be representative of sandstones that are often logged in the relatively large open intervals of wells in these areas. Uncertainties with respect to type and thickness of contributing aquifer intervals precludes meaningful calculation of hydraulic conductivities. Transmissivity values of 0.01 to 0.2 m²/day (1 to 15 igpd/ft) in areas incapable of yielding 0.1 L/s (1 igpm) are considered to be representative of unfractured coal, argillaceous sandstones and siltstones, and shales of the Horseshoe Canyon Formation.

Saskatchewan Gravel and Sand

The major feature containing these deposits is the Vegreville buried valley. As discussed earlier, coarse deposits within the valley are of a discontinuous nature west of Beaverhill Lake. Areas where significant amounts of sand and gravel occur are shown on the main map. East of Beaverhill Lake, reliable lithologic data along the Vegreville Valley is lacking and the inferred 2 to 8 L/s (25 to 100 igpm) yield zone is a qualitative extension of pump testing data near Vegreville and is based on the configuration of the bedrock topography. Reliable borehole and aquifer test data are needed to substantiate this interpretation.

Only two reliable aquifer tests were available for the entire length of the Vegreville Valley. One is about one km north of the map area in Tp 52, R 15, W4 Mer, the other is in SE 11, Tp 51, R 20, W4 Mer. Hydraulic conductivities of approximately 40 m/day (800 igpm/ft²) and 5 m/day (100 igpd/ft²), respectively and safe yields of 15 L/s (200 igpm) and 1 L/s (10 igpm) are indicated by these tests. Apparent yield tests at several other locations produce results within the same range.

Surficial Sediments

A significant number of wells are completed in the area's surficial sediments. These are usually large diameter, shallow, bored wells and obtain water from local sand and gravel lenses within the till. Pumping and apparent tests usually indicated that such lenses may be capable of yielding from 0.1 to 0.4 L/s (1 to 5 igpm) to properly constructed wells. Since water must ultimately enter the lenses from the surrounding till matrix, extrapolation of short term pumping test data over the long term is particularly suspect. Best prospects for these lenses are in the hummocky moraine north of Tp 48.

Reliable pumping test data were not available for the discontinuous, deep (up to 60 m) occurrences of sand and gravel south of the buried valley thalwegs in the hummocky moraine. If the origin postulated for these deposits (movement and redeposition by glaciers) is correct, they cannot be expected to yield high volumes of water because contortion, mixing and compaction would result in permeability substantially lower than that of clean sand and gravel. An apparent yield test in SW 3, Tp 50, R 20, W4 Mer indicated a transmissivity value of 4 m²/day (266 igpd/ft) for sand and gravel from 47 to 55 m.

WATER LEVELS AND GROUNDWATER FLOW DISTRIBUTION

The bulk of the data used in constructing non-pumping water level contours were derived from drillers' reports. Water level measurement from the field survey and pumping tests were given greater emphasis but water levels were not separated with respect to season or time.

Where the Vegreville Valley traverses the map area, contoured water levels are from wells completed in lower portions of valley fill. Elsewhere, only bedrock wells were chosen and a conscious effort was made to contour water levels from wells of similar depth in areas of similar geology. Water levels thus are approximately representative of the map area's various main aquifers. Water levels for the cross-sections were selected from wells which were open to strata over relatively short depth intervals (less than 15 m) and represent an averaged vertical potential distribution as accurately as can be determined with presently available data.

Groundwater flow directions indicated by the water level distribution on the cross-section can only be considered qualitatively, due both to the qualitative nature of the data and the probability that isotropic conditions with respect to hydraulic conductivity are not likely present. Generally, however, flow is from the map area's topographically elevated to depressed areas and is strongly modified by contrasts in hydraulic conductivity.

In the northwestern part of the area, flow is generally from upland areas north and south of the Vegreville Valley towards the valley, then in an easterly direction along the valley. This appears to be true also for bedrock material adjacent to, and underlying, the valley. Flowing wells in areas associated with the valley, and indicated on the main map, were completed in both drift and bedrock aquifers.

Cross-section C-C' indicates that the vertical component of the potential gradient is steepest along the southern Vegreville Valley flank, that groundwater discharge to Cooking Lake is local and originates primarily in the drift, and that downward flow exists under the lake. A similar conclusion was reached by Schwartz (1976) from piezometer installations near Hastings Lake.

The horizontal water level gradient in the Vegreville Valley is steepest just west of Beaverhill Lake. The steep gradient and associated flowing wells of this area may be indicative of a decrease in hydraulic conductivity, perhaps due to the removal or absence of permeable valley fill (as postulated in the surficial geology portion of this report). This interpretation is inconclusive, however, since topography also steepens in the same area.

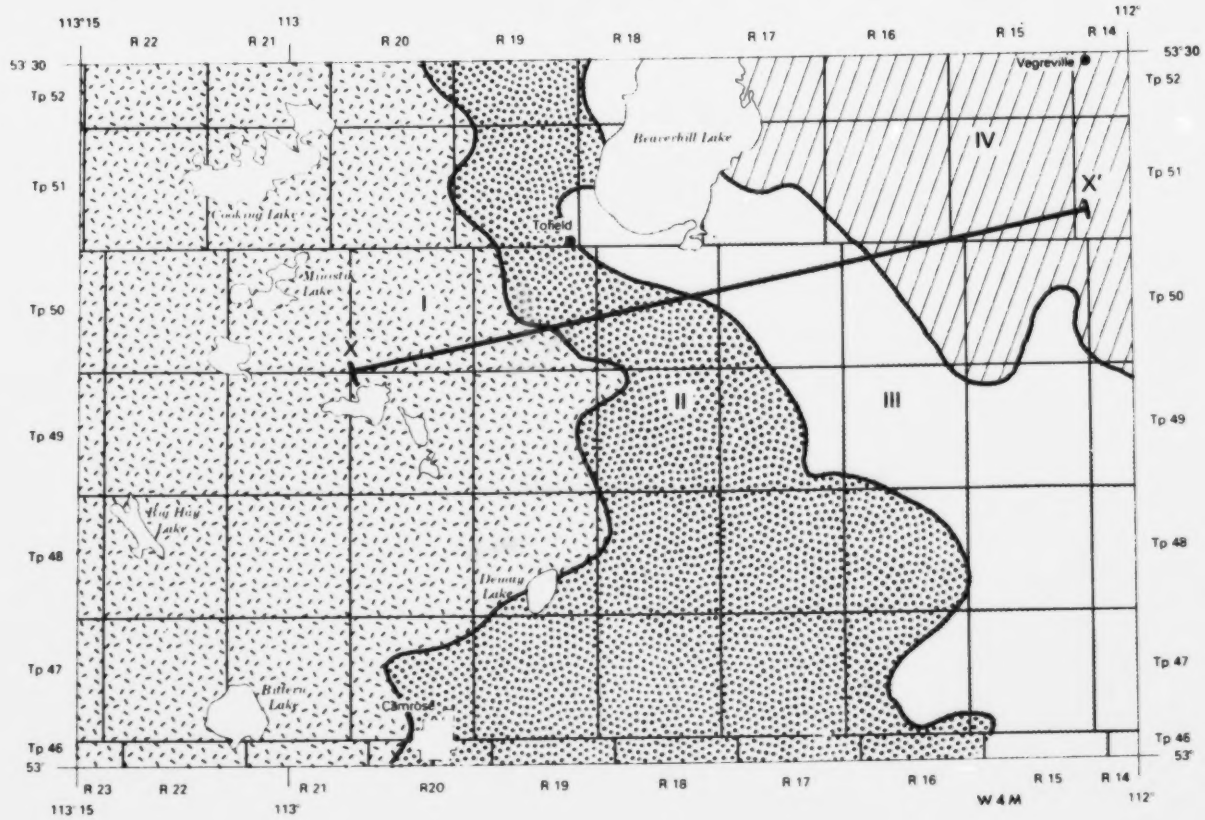
South of Cooking and Hastings Lakes, water levels indicate predominantly recharging conditions but local, closed mounds in water levels indicate that some local groundwater movement towards the various lakes (Miquelon, Joseph, Oliver and Ministik) takes place. Flowing wells, seismic shot-holes and occasional springs at the eastern erosional edge of coal zones of the Horseshoe Canyon Formation indicate that much of the water recharging in the uplands moves downward into the coal zones and then laterally to discharge at their subcrops. The relatively low permeability of underlying Bearpaw and Belly River strata enhances this situation.

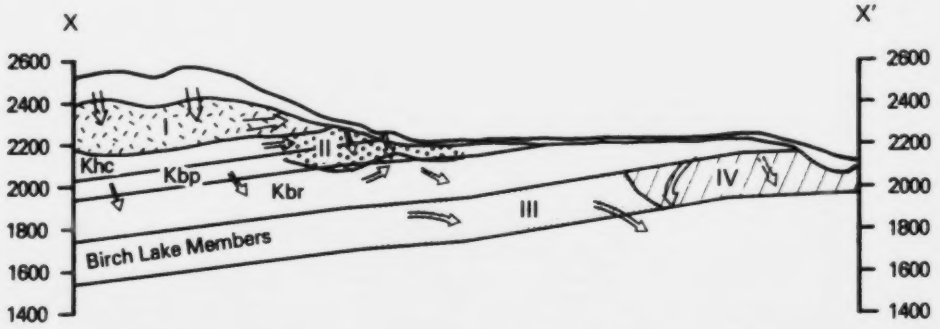
HYDROCHEMISTRY

Chemical composition of groundwaters within the map area is shown in two ways: the areal distribution of major ion constituents is shown on side maps and vertical changes appear on cross-sections. Drift and bedrock water chemistry is shown separately and further, chemistry of waters within the Vegreville buried valley is that of lower portions within the valley fill. Fluoride content appears on separate side maps.

Distribution of "bedrock water" major ion content has a distinct pattern and can be related to position within the various aquifers and groundwater flow systems. Four major areas of distinct bedrock water chemical composition can be recognized (Figure 1):

1. Generally, in the western half of the map area, comprising portions of the Elk Island High and underlain by Horseshoe Canyon strata, most wells produce sodium bicarbonate water and only occasionally waters with sulfate or chloride as dominant anions. Chloride ion is only dominant in water at depths greater than approximately 75 m and sulfate at depths of 15 to 45 m. Total dissolved solids content is usually less than 1500 mg/L, occasionally less than 1000 mg/L, and exceeds 2000 mg/L only in areas of high sulfate or chloride content. These waters are interpreted to be recharged locally on the Elk Island High. Some discharge along the eastern edge of the Elk Island High while other, lesser amounts, enter deeper strata and then flow easterly and northeasterly to constitute portions of waters within other, stratigraphically lower aquifers.
2. The Elk Island High area of bicarbonate bedrock groundwater is fringed to the east by a band having waters of extremely variable composition. Waters with bicarbonate, sulfate, and chloride as dominant





Khc Horseshoe Canyon Fm.
Kbp Bearpaw Fm.
Kbr Belly River Fm.

I: $NaHCO_3$ zone; TDS less than 1500 mg/L
II: Mixed zone; TDS less than 1500 to 4000 mg/L
III: NaCL zone; TDS 1500 to more than 8000 mg/L
IV: $NaHCO_3$ zone; TDS less than 1000 mg/L

FIGURE 1. Chemical zonation of bedrock waters.

anions are distributed in a characteristically spotty fashion; chloride waters are situated in westernmost portions of the area. The band lies for the most part within the area of subcrop of lowermost Horseshoe Canyon and Bearpaw strata and surface elevations are roughly between 730 and 700 m. Wells are usually shallow and only occasionally exceed 30 m in depth. Total dissolved solids content is usually less than 1500 mg/L in areas of bicarbonate waters, 2000 to 3000 mg/L in areas of sulfate waters, and 2000 to occasionally more than 4000 mg/L in areas of chloride waters. Two sources are postulated for these waters. The shallow, chloride waters are waters within intermediate flow systems which originate on the Elk Island High and come near to, and in some cases discharge at, the ground surface stratigraphically and topographically below the bicarbonate discharge zones mentioned in (1) above. The sulfate and bicarbonate waters of this area are waters which circulate locally, within the area of highly variable hydrochemical composition.

3. East of the hydrochemically heterogeneous area, and trending northwest to southeast, is a major zone characterized by chloride groundwaters with total dissolved solids contents varying from about 1500 mg/L in the east to more than 8000 mg/L in the west. Wells in this area are commonly from 60 to 110 m deep and draw water from sandstones of the Birch Lake Members of the Belly River Formation, these being the shallowest strata capable of yielding sufficient quantities of groundwater for domestic or livestock supply. These waters are part of a regional system originating at the Elk Island High and flowing in an easterly direction under the intermediate and local systems previously mentioned. Decreases in chloride and total dissolved solids content to the east in this zone result from increasing portions of the water within the Birch Lake Members being either mixed with locally recharged waters, or from downward displacement of the regional system by local systems. This phenomenon is especially well illustrated by the chemical and water level distributions in cross-sections A-A' and B-B'.
4. In the northeast corner of the map area, and situated under a northwest to southeast trending groundwater divide, Birch Lake Member sandstones still constitute the most often used aquifers. Here, however, their contained waters are of the bicarbonate type with a total dissolved solids content usually less than 1000 mg/L. Due to the southwest dip of geologic strata, Birch Lake Member sandstones are slightly shallower in this area than in the chloride zone, adjacent and to the southwest. Chemical parameters evaluated in this area are thus of waters from wells that are commonly from 30 to 80 m deep. Bicarbonate waters in this zone are recharged locally and displace the chloride-rich waters in Birch Lake Member strata adjacent and to the southwest.

Chemical analyses for drift waters are available in only portions of the map area, reflecting:

(a) the fact that the drift cover is thin and does not contain extensive or highly productive aquifers in much of the area, and
(b) that bedrock waters are usually considered to be superior to drift waters in terms of potability because of generally lower hardness and iron content.

In the band of drift water chemistry extending southeast from Beaverhill Lake, drift thickness is for the most part less than 8 m. Some of the chemical parameters contoured in this area may in fact be those of bedrock waters up to 8 m below the bedrock surface or of mixed, drift and near-surface bedrock waters. A lack of lithologic and completion details for most of the area's shallow wells does not allow conclusions about bedrock or drift source to be reached. These waters are generally of the sodium sulfate type but occasional areas of bicarbonate and mixed (bicarbonate, sulfate, and sometimes chloride) waters occur. Total dissolved solids content is highly variable, ranging from less than 1000 to more than 4000 mg/L. Occasional local areas of extremely high (more than 10 000 mg/L) total dissolved solids content exist.

Water within lower portions of the area's buried valley system has been considered separately from that in glacial drift; isograms are therefore not continuous across valley boundaries. The buried valley system contains sodium bicarbonate water in deeper and central portions (determined from wells 35 to 60 m deep), and occasionally sodium sulfate water near channel edges. Total dissolved solids content ranges from less than 1000 to more than 1500 mg/L.

Drift waters with calcium and magnesium as the dominant cations are generally restricted to shallow zones in areas where downward vertical flow components exist. They are thus prevalent on higher portions of the Elk Island High, adjacent to the Vegreville Valley, and occasionally in shallow zones above deeper Vegreville Valley

fill. In general, the calcium and magnesium type waters have bicarbonate and sulfate as their associated anions. Total dissolved solids content is usually less than 1500 mg/L and often less than 1000 mg/L.

CONCLUSIONS

Aquifers within the map area are capable of yielding from less than 0.1 to 8 L/s (<1 to 100 igpm). Highest yields are from coals of the Horseshoe Canyon Formation and where these are sufficiently fractured (as in the northwestern portion of the map area), they are capable of yielding from 0.4 to 8 L/s (5 to 100 igpm). Unfractured coal zones and portions of the Horseshoe Canyon Formation which do not contain coal are generally only capable of sustained production in the range of 0.1 to 0.2 L/s (1 to 2 igpm). Wells completed in the Bearpaw Formation and uppermost 50 m of the Belly River Formation are generally incapable of producing 0.1 L/s (1 igpm). Best prospects for groundwater within the Belly River Formation are sandstones of the Birch Lake Members, from about 50 to 100 m below the top of the formation. Few pumping tests are available for this zone but apparent yield tests indicate that from 0.1 to 1.5 L/s (1 to 20 igpm) can usually be obtained.

The buried Vegreville Valley extends west to east across the northern portion of the map area and constitutes its most promising drift aquifer. Test drilling west of Beaverhill Lake, however, has shown that permeable valley fill is discontinuous and further drilling east of the lake is required to substantiate the 2 to 8 L/s (25 to 100 igpm) yield category postulated for deposits within the buried valley. A significant number of wells are completed in sand and gravel lenses within the area's till cover. These are usually only capable of producing in the 0.1 to 0.4 L/s (1 to 5 igpm) range since water must ultimately enter the lenses through till of low hydraulic conductivity.

Four areas with chemical characteristics distinctive of near-surface bedrock aquifers exist in the map area. Bedrock waters of the western half of the area are generally of the sodium bicarbonate type with a total dissolved solids content of less than 1500 mg/L. A band of highly variable characteristics fringes the eastern boundary of the first area and contains a mixture of sodium chloride, sulfate, and bicarbonate waters with total dissolved solids contents from less than 1500 to more than 4000 mg/L. A zone of sodium chloride bedrock water with total dissolved solids content as high as 10 000 mg/L extends in a southeasterly direction from Beaverhill Lake. Finally, a zone of sodium bicarbonate water with a total dissolved solids content of less than 1000 mg/L exists northeast of the sodium chloride zone. The distribution of these regions of distinct hydrochemistry is related to position within the area's various bedrock aquifers and groundwater flow systems.

Water within lower portions of the area's buried valley system is generally of the sodium bicarbonate type with total dissolved solids of less than 1500 mg/L. Shallow drift waters in the western upland region are usually of the calcium-magnesium bicarbonate type; in the central, low-lying area they are of the sodium sulfate type with total dissolved solids occasionally exceeding 4000 mg/L.

REFERENCES

Alberta Environment, Planning Division (1976): Cooking Lake area study; v. II: Water inventory and demands.

Alberta Environment, Pollution Control (1978): Edmonton regional utilities study; v. IV: Groundwater.

Alberta, Government and University (1969): Atlas of Alberta; University of Alberta Press in association with University of Toronto Press, 158 pages.

Allan, J.A. and J.O.G. Sanderson (1945): Geology of Red Deer and Rosebud sheets, Alberta; Report 13, Edmonton: Alberta Research Council. 109 pages.

Bayrock, L.A. (1972): Surficial geology of the Edmonton map sheet, NTS 83H;scale 1:250 000, Edmonton: Alberta Research Council.

Bayrock, L.A. and G.M. Hughes (1962): Surficial geology of the Edmonton district, Alberta; Report 62-6, Edmonton: Alberta Research Council. 40 pages.

Bowser, W.E., A.A. Kjearsgaard, T.W. Peters and R.E. Wells (1962): Soil survey of Edmonton sheet (83H); University of Alberta Bulletin SS-4; Alberta Soil Survey Report 21, 66 pages.

Campbell, J.D. (1975): Coal resources, Tofield-Donalda area, Alberta; Report 75-8, Edmonton: Alberta Research Council. 64 pages.

Carlson, V.A. (1966): Bedrock topography and surficial aquifers of the Edmonton district, Alberta; Report 66-3, Edmonton: Alberta Research Council. 21 pages.

Domenico, P.A. (1959): Geology and groundwater hydrology of the Edmonton Formation in Central Alberta, Canada; Syracuse University M.Sc. thesis, 125 pages.

Elliot, R.H.J. (1958): Sub-surface correlation of the Edmonton Formation; Edmonton Geological Society Quarterly, June 1958, pp. 1-6.

Emerson, Donald (1977): The surficial geology of the Cooking Lake Moraine, east-central Alberta, Canada; University of Alberta M.Sc. thesis, 116 pages.

Farvolden, R.W. (1961): Groundwater resources, Pembina area, Alberta; Report 61-4, Edmonton: Alberta Research Council. 26 pages.

------(1963): Bedrock topography, Edmonton-Red Deer map area, Alberta; *in* R.N. Farvolden, W.A. Meneley, E.G. LeBreton, D.H. Lennox and P. Meyboom; Early contributions to the groundwater hydrology of Alberta; Bulletin 12, Edmonton: Alberta Research Council. p. 57-62.

Green, R. (1972): Geological Map of Alberta; scale 1:267 000, Edmonton: Alberta Research Council.

Irish, E.J.W. (1970): The Edmonton Group of south-central Alberta; Bulletin of Canadian Petroleum Geologists, v. 18, no. 2, pp. 125-155.

LeBreton, E.G. (1963): Groundwater geology and hydrology of east-central Alberta; Bulletin 13, Edmonton: Alberta Research Council. 64 pages.

Longley, R.W. (1968): Climatic maps for Alberta; Edmonton: University of Alberta, 8 pages.

------(1972): The climate of the prairie provinces; Environment Canada, Atmospheric Environment, Climatology Studies 13, 79 pages.

Matheson, D.S. and Thomson, S. (1973): Geological implications of valley rebound; Canadian Journal of Earth Sciences, v. 10, no. 6, pp. 961-978.

Ower, J.R. (1958): The Edmonton Formation; Edmonton Geological Society Quarterly, March, 1958, pp. 3-11.

Rutherford, R.L. (1939a): Tofield, Alberta; scale 1:253 440, Map 505A, Geological Survey of Canada.

------(1939b): Edmonton, Alberta; scale 1:253 440, Map 506A, Geological Survey ofCanada.

Shaw, E.W. and S.R.L. Harding (1949): Lea Park and Belly River Formations of east-central Alberta; Bulletin of American Association of Petroleum Geologists, v. 33, pp. 487-499.

Schwartz, F.W. (1976): Groundwater studies in the Cooking Lake Moraine area of Alberta; Unpublished contract report for Environment Canada, 47 pages.

Stein, R. (1976): Hydrogeology of the Edmonton area (northeast segment) Alberta; Report 76-1, Edmonton: Alberta Research Council. 21 pages.

Steiner, J., G.D. Williams and G.J. Dickie (1972): Coal deposits of the Alberta Plains; Proceedings, First Geological Conference on Western Canadian Coal, Edmonton, Information Series 60, Edmonton: Alberta Research Council. pp. 85-108.

TransAlta Utilities Corporation (formerly Calgary Power Ltd.) (1973): Camrose-Ryley project: Application to the Energy Resources Conservation Board to develop Roundhill Mine; Sec. II, Exploration report.

------(1975): Camrose-Ryley project: Application to the Energy Resources Conservation Board to develop Roundhill Mine; Section V, Environmental report, Vol. III.

Westgate, J.A. (1969): The Quaternary geology of the Edmonton area, Alberta; *in* S. Pawluk, *ed.*, Symposium, Pedology and Quaternary Research; National Research Council of Canada and University of Alberta; pp. 129-151.